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REPORT NO. 361

DESIGN AND COMPARATIVE BALLISTICS OF
NEW EXPERIMENTAL CONCRETE PRACTICE BOMBS WITH
DRUM-TYPE AND SMALL AND LARGE BOX-TYPE FIN ASSEMBLIES
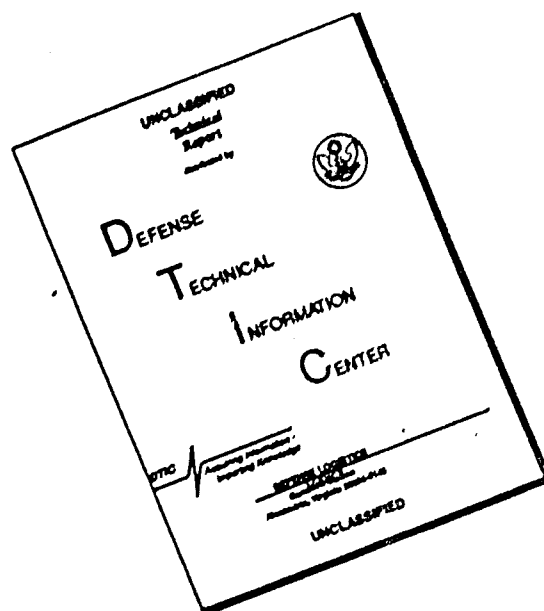
by

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DESIGN AND COMPARATIVE BALLISTICS OF NEW EXPERIMENTAL CONCRETE PRACTICE

BOMBS WITH DRUM-TYPE AND SMALL AND LARGE BOX-TYPE FIN ASSEMBLIES

Abstract

Qualitative description of the theory used in design of practice
and demolition bombs is given briefly in this report. The known
important factors to be considered in fin design are discussed.
The results obtained from ballistic tests with drum-type and small
and large box-type fin assemblies are given. The drum-type fin is
aerodynamically superior to the box-type and a box-type with small
fin diagonal is superior to a box-type with large fin diagonal.

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I. Introduction

A series of proof tests of strength and of flight characteristics of a group of concrete practice bombs manufactured by the Concrete Products Company of America was conducted at the Aberdeen Proving Ground. Upon completion of the tests it was considered that the bombs as originally submitted were capable of considerable improvement, and representatives of the Concrete Products Company of America were referred to the Ballistic Research Laboratory by Lt. Col. R. G. Shinkle for advice on fin design.

The Theory Section of the Exterior Ballistics Branch of this Laboratory made several recommendations. Only slight changes on the body of the bomb were considered desirable, but it was recommended that the fin structure be modified by moving the leading edge further back and by making the fin box smaller. It was also recommended that a British drum type fin assembly be constructed, and drawings of several British bombs were shown as examples.

Two fin assemblies were then designed by Mr. G. D. Mateer of the Concrete Products Company of America. One was of box type, with a fin box diagonal of length 6.72", which appeared to be the smallest box which would permit convenient handling of the spotting charge assembly. The other fin assembly was of drum-type, with certain modifications on the connecting strut design. Both designs were considered by the Theory Section to be very promising.

It was suggested that fin assemblies of both types be constructed and tested. Upon conversation with Mr. H. S. Beckman upon the subject of construction and test of the bombs, Mr. Beckman suggested that a design also be made incorporating a fin box having an 8.5" diagonal which is the length of the diagonal of the fin box of the Bomb, G.P., 100lb., M30. This was considered a very desirable project, not only from the point of view of obtaining a good fin design, but also because definitive evidence upon the question of effect of fin box size upon drag could be obtained.[1] Accordingly, 30 bombs were manufactured, having identical bodies, with 10 of each of 3 fin designs. Schematic drawings of these bombs are given in Figure 8 of this Report. The two designs using box fins are identical except for width of fin box, the third design being the British type.

The ballistic tests on these bombs are now complete. In view of the fact that not only the prime purpose of the program, obtaining a sound design for the concrete bomb, has been accomplished, but also valuable information on design has been obtained, it appears proper to devote some attention to the relation of these tests to known principles of bomb design and to analyze with some care the results of the tests.

1. It was predicted by Col. H. H. Zornig upon the basis of plots of form factors against the ratio of the fin box diagonal to the diameter of the bomb that the diagonal across the fin box was of great influence on the drag.

II. Some Principles Used in Design of Practice Bombs.

1. Preliminary Statements.

The forces on a bomb which is held rigidly at an angle δ to the direction of flow of an airstream are shown schematically in Figure 1. The total resistance offered by the bomb has components D = Drag and L = Lift measured respectively along and perpendicular to the airstream. There will also be a moment M tending to align the bomb's axis with the direction of the airstream. The center of pressure is defined to be that position on the axis of symmetry of the bomb where D and L would have to be applied in order to result in the couple M.

In order to make comparisons on bombs which will be independent of the size of the bomb, it is desirable to define dimensionless aerodynamic coefficients as follows:

FIG. 1

1.1
$$K_D = D/\rho d^2 u^2$$

$$K_L = L/\rho d^2 u^2 \sin \delta$$
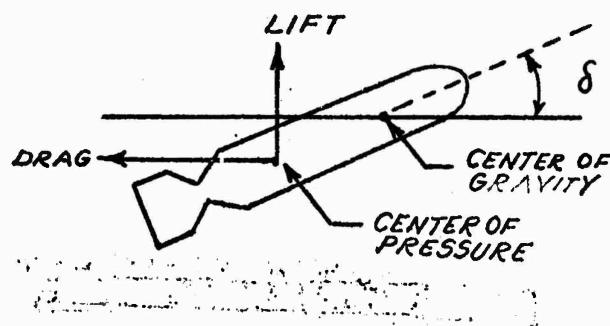
$$K_M = M/\rho d^3 u^2 \sin \delta .$$

Here ρ is the density, d the diameter and u the velocity of the airstream. The coefficients are functions of δ, of Mach number and of Reynolds number. However, if K_D is written $K_{D_0}(1 + K_{D\delta}\delta^2)$, the coefficients K_{D_0}, $K_{D\delta}$, K_L and K_M are sensibly constant for most bombs for u between 50 and 300 ft./sec. and for δ less than 10°. In comparisons of "drag" the numbers K_{D_0} will be the criterion of comparison. The distance from the center of pressure to the center of gravity is easily seen to be $dK_M/(K_L \cos \delta + K_D)$, or, since K_D is small in comparison to K_L, for δ small:

1.2   Center of pressure distance $= dK_M/K_L$.

The requirements for good bomb design can now be formulated simply. The prime requirement is that K_M be large enough to give a definite margin of stability. The second requirement is that K_D be as small as possible consonant with strength of structure and ease of manufacture. The foregoing requirement is set not because of the inherent desirability of low drag, but because the dispersion due to accidents of launching, wind gusts, etc., varies almost directly as the drag.

In addition to the forces and couple so far discussed there are also forces and couples which vanish when the angular velocity is zero. These are called "dynamic" forces and couples in contradistinction to D, L, and M which are called the "static" forces and couple. A discussion of the importance of the dynamic forces and couples is beyond the scope of this report.

2. World War Bomb Design.

At the time of the World War emphasis was placed almost exclusively on the design of the body of the bomb. The forms developed by the United States Army at that time were based on the form of Eiffel dirigible IV. The form is that obtained by revolving a curve consisting in part of an ellipse and in part a parabola. (See Figure 2). The fin structure consisted of four vanes, with braces on the vanes of the heavier bombs.

ELLIPSE   PARABOLA

$\frac{1}{3}$ $\frac{2}{3}$

EIFFEL FORM

FIG. 2

The body form was modified shortly after the War to the tear drop design. This design is obtained by joining sections of two ellipses and a section of straight line in such a manner as to form a smooth curve. The surface of revolution of this curve is the tear drop form (See Figure 3).

Both the Eiffel form and the tear drop form were expensive to manufacture. Furthermore, the presence of fuzes, lugs, and especially the fin structure made insignificant the gain in aerodynamic efficiency of these types over the simpler forms. For one type of bomb Dr. E. J. Loring stated[1] that the drag of the bomb body alone was only 58 per cent of the drag of the complete bomb. Accordingly, a cylindrical body with elliptical ogive and conical after body was designed by Dr. Loring. This combined ease of manufacture with adequate aerodynamic characteristics. Most modern bombs make use of the Loring design for the bomb body. A further discussion of this design is contained in the following section.

.36

MAX. WIDTH

.1   .45   .45
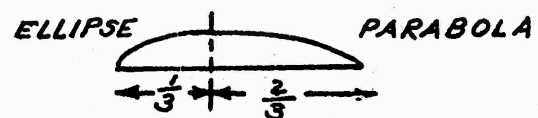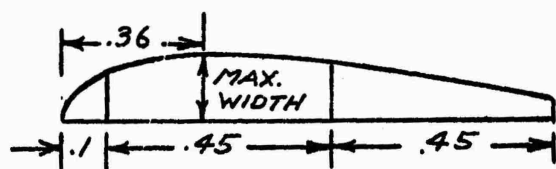
TEAR DROP FORM

FIG. 3

1. "Bombs, Their Flight, Action, Test and Design". Lecture given at Picatinny Arsenal, Dover, N. J., November 5 and 6, 1924, by E. J. Loring.

3. Measurements Made by H. L. Dryden.[1]

Wind tunnel tests were conducted at the U. S. Bureau of Standards by Dr. H. L. Dryden upon a number of bomb models. These included a series of designs by Captain Frank Short, as well as models of a number of standard bombs. Certain of the results will be reviewed here briefly.

   a. Effect of Ogive Shape.

The shape of ogive is of not too great importance as long as there are no sharp corners and the nose is not too blunt. An ogive of about one diameter length, with elliptic section appears to be satisfactory.

   b. Effect of body shape.

The Loring design (See Figure 4) differs little aerodynamically from tear drop designs. In one case, for flat fins without braces, there was 12 per cent difference in drag between a tear drop form and a cylindrical form. When fin braces were added there was no perceptible difference between the two types.

LORING   DESIGN

FIG. 4

For minimum drag the angle a between the tail cone and the cylindrical side should be between $12°$ and $15°$. (It is of interest to note that for shell a $7°$ boattail has been considered optimum).

   c. Effect of fin braces.

Streamlined braces increase the drag by roughly 50 per cent, while cylindrical or angle braces double the drag. The drag on a bomb with cylindrical fin braces is about the same as that on a bomb body which has been cut off above the tail cone.

   d. Fin design.

For models with simple vane type fins the fin drag was at least 30 per cent of the total drag. For a bomb body without fins the center of pressure was found to be from 1/3 to 2/3 body length ahead of the nose, so that considerable fin action is required for stabilization. The importance of fin design is then clear.

The "fin force" was found to act at approximately the leading edge of the fin. The following fin designs were found to be successful:

1. The following is taken from "Aerodynamics of Aircraft Bombs" by Hugh L. Dryden. Bureau of Standards, 1927.

(1) Cross blade fins, with leading edge of fins well back, with considerable fin area, with no
braces. (Structural considerations
in many cases prevent use of this
design).
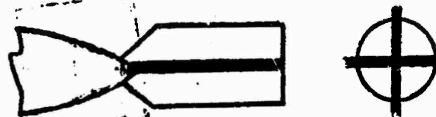
(2) Cross blade fins with "napkin ring" brace.

FIN ASSEMBLIES

(3) Cross blade fins with cylindrical brace.

FIG. 5

(4) Loring box type fins.
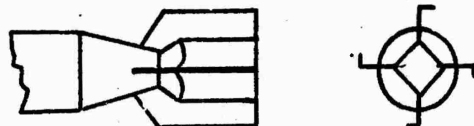
(Note: (2) and (3) are from
Captain F. Short's series).

4. Effect of Skin Friction on Drag[1]

A recent study was made by R. H. Kent of the effect of skin friction on the drag of bombs. The form factor i of a bomb is de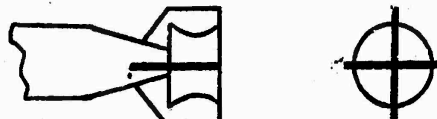fined to be the ratio of its drag coefficient corresponding to zero-yaw, K_{D_0}, to the Cavre drag coefficient K_{D_q}. The form factor as deduced from time of flight measurements is i_T and as deduced from range measurements is i_X. Figure 6 shows i_T and i_X against the ratio of the total surface area to the square of the diameter for a series of bombs. The values of i_T and i_X are those deduced from range bombings at 10,000 foot altitude at an airspeed of 160 mi./hr.

Examination of the graphs shows evidence of a trend toward increase of form factor, and hence of drag, with increase of surface area. This would tend to indicate that skin friction drag forms an important part of the total drag on a

1. The following material is taken from Ballistic Research Laboratory
Memorandum Report No. 74, "Form Factors of Bombs as Dependent on
Their Surface Ratios", by R. H. Kent.

COMPARISON OF FORM FACTORS WITH SURFACE AREA
FOR CYLINDRICAL DEMOLITION AND PRACTICE BOMBS

Y = 10,000 FT.

i_X FORM FACTOR WITH RESPECT TO RANGE;

i_T FORM FACTOR WITH RESPECT TO TIME OF FLIGHT;

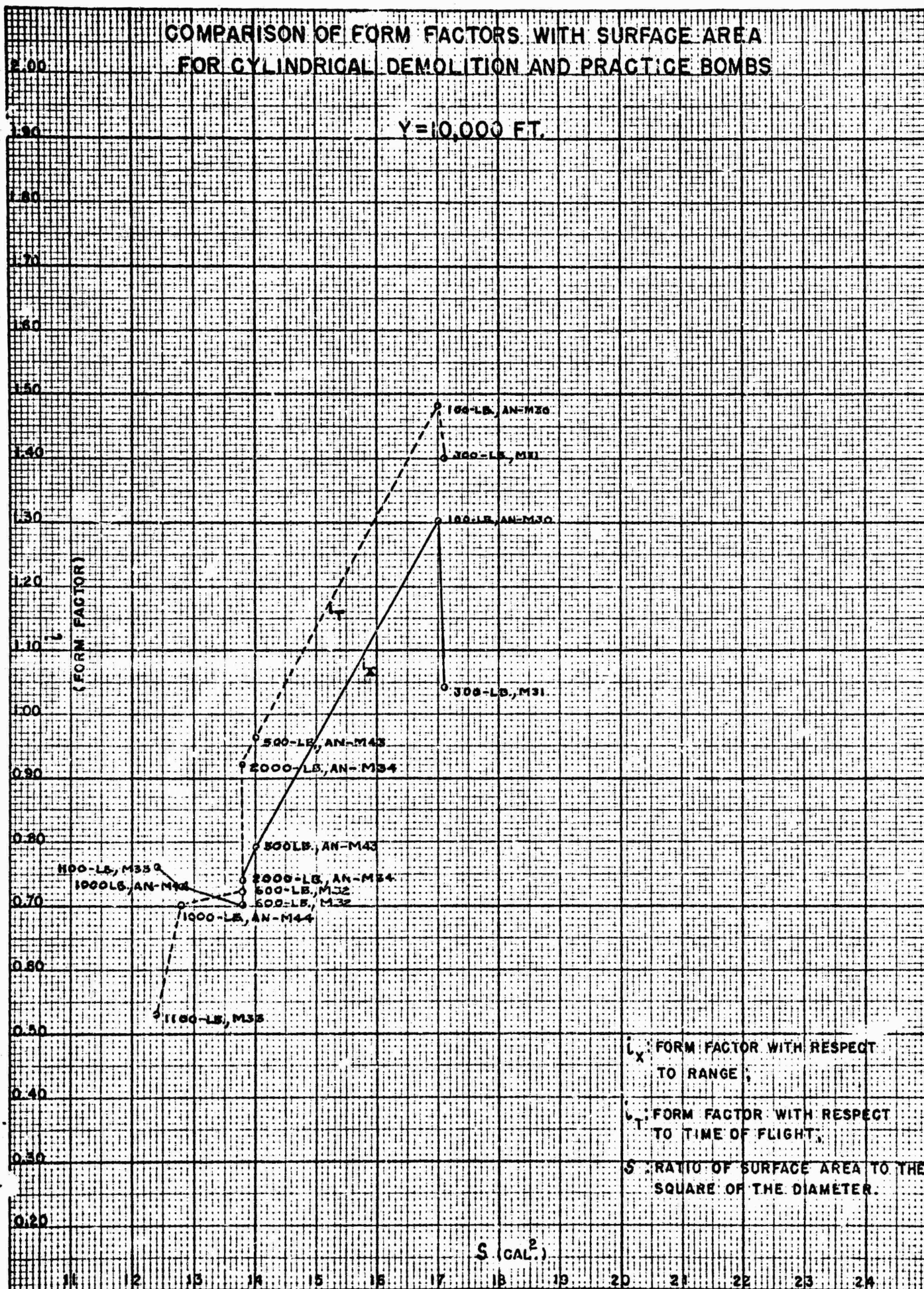S RATIO OF SURFACE AREA TO THE SQUARE OF THE DIAMETER.

FIGURE 6

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bomb. [In the case of artillery shell, skin friction drag is about 15 per cent
of the total drag.[1]]

Although it is undoubtedly true that skin friction is an important part
of the total drag on the bomb, the graph shown requires careful interpretation.
The series of bombs under consideration are not strictly homologous. In
particular, lugs and fuzes are relatively smaller on the larger bombs, and
there are definite differences in fin design. Both of these latter
considerations would tend to order the bombs in approximately the same fashion
as is done by the ratio of total surface to the square of the diameter. The
presence of greater relative protuberance area on the smaller bombs would lead
to relatively greater form drag.

5. Observations made by Colonel H. H. Zornig.

A considerable amount of experimentation was conducted by Colonel
H. H. Zornig on improvement of certain bombs, in particular[2] the Bomb, Practice,
100-lb., M38. The M38 had a smoke bottle for spotting purposes held in a cage
in the fin box and "belly bands" to which the suspension lugs were attached.
It was found that the bottle and cage were responsible for 20 per cent of the
drag, and that the belly bands were responsible for an additional 26 per cent
of the drag. (This effect of belly bands has since been verified in other
experiments.)

It was also surmised by Colonel Zornig that a large fin box contributed
appreciably to the drag. Figure 7 shows a graph of i_T and i_X against the
ratio of the width of the fin box diagonal to the diameter, and indicates that
this is the case. This evidence is, however, subject to somewhat the same
objections raised in the last paragraph of the preceding section, namely,
the comparison is not a comparison of homologous bombs. The question of
effect of fin box width will be fully discussed in the analysis of the results
of the tests of concrete practice bombs. This experiment gave definitive
evidence upon the question.

6. Brief Summary of Current Information on Body and Fin Design.

a. Effect of Ogive Shape.

If dynamic forces and torques are ignored, as long as the
nose is not too blunt, and there are no sharp corners, the ogive shape is
not of critical importance in bomb design.

b. Effect of Belly Bands.

If belly bands are used the drag will be increased by from
15 to 25 per cent. This method of attaching suspension lugs is particularly
unfortunate for semi-armor-piercing and armor piercing types, where a high
striking velocity is desired.

1. See Ballistic Research Laboratory Report No. 287, "The Relation Between
    Skin Friction Drag and the Spin Reducing Torque," by A. C. Charters and
    R. H. Kent.
2. An account of some of this work can be found in Ballistic Research Laboratory
    Report No. 73, "A Study of Methods by Which the Air Resistance of the
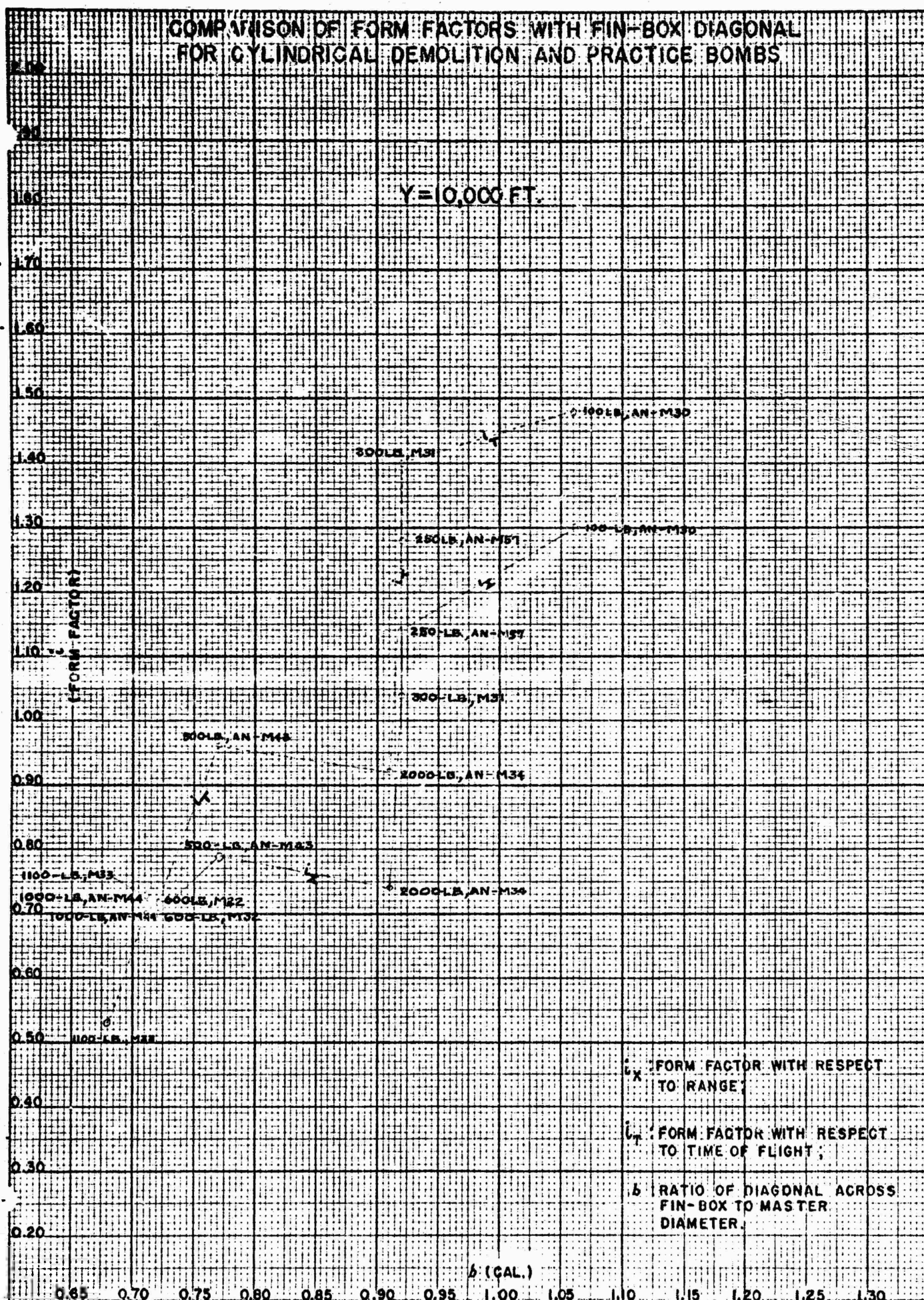   100-lb. Practice Bomb M38 (T2) Can be Reduced", by H. P. Hitchcock.

COMPARISON OF FORM FACTORS WITH FIN-BOX DIAGONAL
FOR CYLINDRICAL DEMOLITION AND PRACTICE BOMBS

FIGURE 7
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c. Effect of Body Shape.

In view of the fact that the fins account for at least 30 per cent of the drag, and in view of manufacturing difficulties, the cylindrical body with conical tail section gives satisfactory results. The optimum angle between tail cone and side is probably between 12° and 15°. The effect of length of tail cone is not precisely known.

d. Fin Design.

A cross blade fin without braces and with leading edge well back gives excellent results in cases where this design is practicable. (For example the Bomb, Fragmentation, 20-lb., M41).

On box type fins the leading edge should be as far back as practicable. A small fin box gives definitely less drag than a large box.

On at least one body the British drum type tail assembly gives better results than the box type. The leading edge of the drum should be well back from the body. The British rule of thumb is that the length of the drum be equal to the diameter.

In some cases stability has been achieved by adding a circular shroud or drum around the blades of a cross blade fin structure. This is particularly useful when the fin structure is not to extend beyond the sides of the bomb.

7. Design of an Experiment with Concrete Practice Bombs with Fins of Three Different Types.

As stated in the introduction ten (10) bombs with tail assemblies of each of three types were constructed. Drawings of these bombs appear on Figure 8.

The bomb bodies are identical in all three designs. The bodies are of solid concrete, with a cavity for the spotting charge and with the lugs and the bolts for the tail assembly set in the concrete. The tail assembly is attached to a cap which in turn is bolted to the body. The fin designs were of the three types, box type with large fin box, box type with small box and British drum type.

It was the opinion of the Theory Section of the Ballistic Research Laboratory that these designs had several features known to be desirable. In particular, the body shape presents no sharp corners and the conical section makes an angle of 10° with the side of the bomb. The absence of nose fuze and the small lugs also contribute aerodynamically. The back of the bomb body presents only those obstructions to the air flow which are necessitated by the spotting charge.

The leading edge of the fins is well to the rear of the bomb body in all three cases. It was considered that the small fin box would probably have low drag. In the absence of a great deal of evidence on the subject, the British drum type was considered to be an excellent possibility.

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EXPERIMENTAL CONCRETE PRACTICE BOMBS WITH THREE
DIFFERENT FIN ASSEMBLIES.

BOX-TYPE
WIDE FIN DIAGONAL

LENGTH, OVERALL .... 38½"
TOTAL WEIGHT .... 103¾ lbs.
DISTANCE FROM NOSE TO C. OF G. .... 14¾"
DISTANCE FROM C. OF G. TO LEADING EDGE
   OF FIN .... 17¼"
DIMENSIONS OF BOX ON FIN, IDENTICAL TO M-30
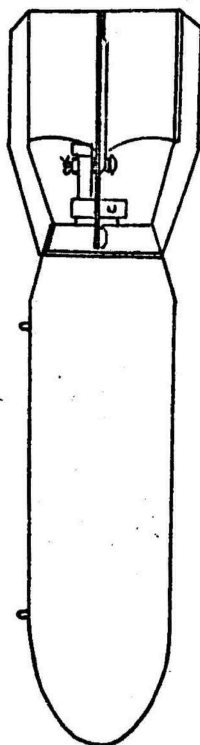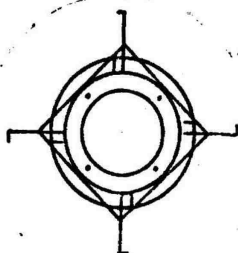
BOX-TYPE
NARROW FIN DIAGONAL

LENGTH, OVERALL .... 38½"
TOTAL WEIGHT .... 103¾ lbs.
DISTANCE FROM NOSE TO C. OF G. .... 14¾"
DISTANCE FROM C. OF G. TO LEADING
   EDGE OF FIN .... 17¼"
DIMENSIONS OF BOX ON FIN, 4¾" SQUARE,
OTHER DETAILS SAME AS DESIGN NO. I
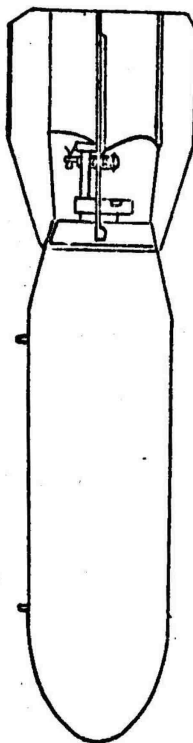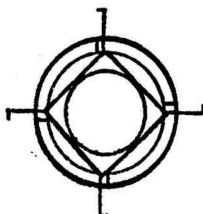
DRUM TYPE

LENGTH, OVERALL .... 45½"
TOTAL WEIGHT .... 104 LBS.
DISTANCE FROM NOSE TO C OF G. .... 15½"
DISTANCE FROM C. OF G. TO LEADING
   EDGE OF FIN .... 22"

FIGURE _ 8   _12_
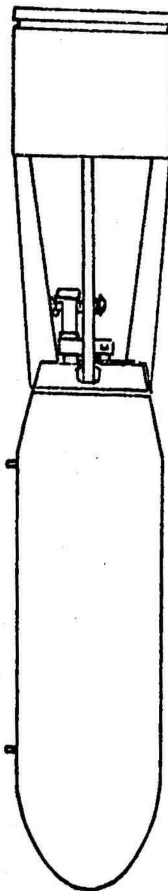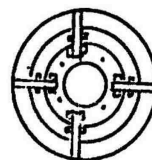
It is to be remarked that Mr. Mateer's design of the connecting struts on the British type assembly appears to give very smooth contours. The struts are of ⊔ cross section and are attached at the corner of the conical section. This type of construction should cause almost the entire fin force to act on the drum, which is well back of the body.

8. Physical Characteristics of the Concrete Practice Bombs.

It is to be remarked that the weights, center of gravity positions and moments of inertia of the concrete bombs dropped at the Proving Ground were remarkably consistent. These data are given, together with corresponding data for the AN-M30 and M38A2 in Appendix A. In each case the standard deviation of the measured quantity is much smaller for the concrete bombs than for the AN-M30 and M38A2.

This uniformity is perhaps not of too great importance in so far as it affects bombing with practice bombs at the Proving Ground. However, it has come to the attention of the Laboratory that the Bomb, Practice, M38A2 has not always been loaded to prescribed weight in the field. In one instance, bombs loaded at one station averaged 4 lbs. underweight and there have been instances of larger discrepancies. Due to variation in density of sand in various sections of the country loading to prescribed weight is sometimes exceedingly difficult. The effect of this variation in weight is to cause systematic error in bombing. An average of 7 lbs. too little sand for the M38A2 would result in a systematic target error of about 5 mils at the airspeeds now most commonly employed in service. It is believed that use of concrete practice bombs would prevent errors due to this cause.

A possible advantage of the drum type over the box type fins should be noted. According to Captain F. D. Atkinson, of the Armament Laboratory at Wright Field, certain types of under wing bomb racks require that the suspension lugs on bombs with box type fins be moved around 45° from their normal position. This would be unnecessary with the drum type fin.

III. Comparison of the Experimental Results Obtained from Dropping Concrete Practice Bombs with Three Different Types of Fin Assembly.

1. Data Obtained From Differential Ranges and Times of Flight.

Of the 30 bombs used, each of 4 was dropped in a two-bomb salvo with a standard Bomb, G.P., 100-lb., AN-M30. These four were all of the drum type since less was known about this type than any other, and the salvo method offered the most direct comparison. In each of these four salvos the drum type yielded a greater or an equal range and a shorter or an equal time of flight, the mean difference in range being 76 feet and that in time of flight 0.15 seconds for an altitude of 10,000 feet. The results on time of flight are not conclusive, being based on stop-watch readings.[1]

1. These measurements are given in Appendix B.

The smaller retardation for the bombs with drum-type fins was in spite of the fact that they were 15 lbs. lighter than the AN-M30 bombs. Of two bombs with identical shapes, moments of inertia and centers of gravity and the same amplitude and period of yaw, the more massive bomb will have a smaller retardation. Let the mass of the lighter bomb be denoted by m_l, the mass of the heavier bomb by m_m, and the reciprocal ballistic coefficients by γ with subscripts corresponding to those used for mass. If the bombs are geometrically and mechanically homologous and have identical yaw, the ratio of the reciprocal ballistic coefficients is given by

$$\frac{\gamma_m}{\gamma_l} = \frac{m_l}{m_m} .$$

The form factor, i, defined by

$$i = \frac{m\gamma}{d^2}$$

reflects directly the relative efficiency of the bombs as shown in the following table.

TABLE I

Form Factor

	From Range	From Time of Flight
AN-M30	1.304	1.482
Drum-Type	0.906	1.159

Since the conditions under which the mass reduction would be correct are not satisfied, only an approximate value of the reduction of retardation can be obtained from Table I. It appears that the drag for the drum type bomb is 31% less than that for the AN-M30 if inferred from range, or 22% less if inferred from time of flight. Of course some of this may be attributed to difference in lugs and absence of fuzes; but it seems reasonably certain that the main difference is due to the type of fin. This decreased drag for the drum fin would result in a decreased trail and time of flight, decreased differential effects, and greater accuracy in bombing, especially from high altitudes.

The difference between the ranges in vacuo and in air is described as the range lag and the difference between the times of flight in air and in vacuo is described as the time lag. These quantities furnish easily intelligible measures of ballistic efficiency. The following table gives a comparison of these elements. "Drum-type as Corrected" refers to the results expected for a bomb with a drum fin with a mass reduction made according to the procedure described earlier.

TABLE II

Altitude of Release 10,000 ft.; True Air Speed of Release 160 mi./hr.

Bomb	Range Lag (ft.)	Time Lag (secs.)
AN-M30	379	1.413
Drum Type as Dropped	303	1.263
Drum Type as Corrected	266	1.106

Thus for comparable bombs, the drum fin may be expected to give a decrease in range lag of 113 feet or 30% and a decrease in time lag of 0.307 seconds or 22% for the conditions noted.

2. Data Obtained from Absolute Measurements of Range and Time of Flight.

Of the 30 bombs whose flight characteristics were to be compared, 4 bombs with drum fins were dropped in the comparative tests just described and one bomb with a drum fin was expended in a handling test. Absolute measurements of the ranges and times of flight of the other 25 bombs were made by means of the Camera Obscura and associated instrumentation[1] and of these fairly conclusive data for 5 bombs with large fin-box diagonal, 9 with small fin-box diagonal and 5 with drum type fins are available at the present date.

The measured ranges and times of flight were reduced to those elements which would have been obtained if there had been no ballistic wind, no ballistic departure from standard air density structure, no climb and no rotation of the earth. The latter quantities, which are described as reduced ranges and times of flight, were then corrected to those values which would have resulted if the actual release had been made from an altitude of 10,000 feet and an air speed of 160 miles per hour. These results, described as standard elements, are tabulated below. The mean standard range lags and time lags and the individual, uncorrected standard deviations of these elements are shown in Table V. Round (1), which is suspected to be a "maverick", was excluded in making the tabulation.

1. The equipment employed in the measurement of ranges, deflections, ground speeds, azimuths of the tracks, and rates of climb is described briefly in Ballistic Research Laboratory Report No. 144, "First Progress Report: On the Accuracy of the Camera Obscura Installation for Obtaining the Initial Data of Bomb Ballistics." The equipment employed in the measurement of time of flight is the Western Electric Camera Clock which is described in Ballistic Research Laboratory Report No. 282, "Calibration and Procedure for Employment of the Western Electric Camera Clock in Determination of the Time of Flight of Bombs."

The equipment employed in obtaining meteorological data included a balloon-theodolite system for the measurement of the magnitude and azimuth of the wind at various altitudes and a raysonde transmitter and receiver for obtaining the pressure, temperature and humidity at various altitudes.

TABLE III

	RANGE (ft.)			TIME OF FLIGHT (secs.)		
Date	Large Fin Diagonal	Small Fin Diagonal	Drum Fin	Large Fin Diagonal	Small Fin Diagonal	Drum Fin
3-8-43	5443	5516		26.355	26.071	
	5617 (1)	5534		26.434 (1)	26.102	
	5456	5520		26.288	26.199	
	5492	5438		26.204	26.235	
	5455	5459		26.404	26.284	
4-24-43		5467	5591		26.086	26.132
		5499	5476		26.069	
		5482	5490		26.137	25.928
		5475	5557		26.072	25.980
			5518			26.098
Mean All Observations	5492	5488	5526	26.347	26.139	26.034
Mean without 1	5462			26.313		
Optimum Estimate of Probable Error of the Mean	21.68	7.11	14.26	0.0323	0.0181	0.0325
Optimum Estimate of Probable Error of the Mean without 1	7.09			0.0292		
Optimum Estimate of the Probable Error of an Individual	48.48	21.33	31.89	0.0722	0.0544	0.0650
Optimum Estimate of Probable Error of an Individual without 1	14.19			0.0585		

The corresponding reciprocal ballistic coefficients are shown in Table IV.

TABLE IV

	RECIPROCAL BALLISTIC COEFFICIENT CORRESPONDING TO RANGE			RECIPROCAL BALLISTIC COEFFICIENT CORRESPONDING TO TIME OF FLIGHT		
Date	Large Fin Diagonal	Small Fin Diagonal	Drum Fin	Large Fin Diagonal	Small Fin Diagonal	Drum Fin
3-8-43	.7752 .4386(1) .7502 .6793 .7519	.6333 .5984 .6242 .7862 .7440		.8130 .8873(1) .7746 .7267 .5297	.6498 .6676 .7236 .7440 .7722	
4-24-43		.7278 .6671 .6988 .7122	.4888 .7092 .6835 .5540 .6289		.6583 .6489 .6868 .6502	.6849 .5669 .5970 .6649
Reciprocal Ballistic Coefficient of Mean	.6785	.6877	.6126	.8036	.6890	.6283
Reciprocal Ballistic Coefficient of Mean without 1	.7392			.7891		
Optimum Estimate of Probable Error of Reciprocal Ballistic Coefficient	0.0423	0.0139	0.0276	0.0136	0.0104	0.0187
Optimum Estimate of Probable Error of Reciprocal Ballistic Coefficient without 1	0.0139			0.0168		
Optimum Estimate of Probable Error of Reciprocal Ballistic Coefficient of an Individual	.0946	.0417	.0618	.0416	.0314	.0375
Optimum Estimate of Probable Error of Reciprocal Ballistic Coefficient of an Individual without 1	0.0278			0.0336		

TABLE V

Fin Type	(1) Large Fin Diagonal	(2) Small Fin Diagonal	(3) Drum-Type Fin
Range Lag	391	365	327
	(1)-(2) 26	(2)-(3) 38	(1)-(3) 64
Uncorrected Individual Standard Deviation of Range Lag	18.2	29.8	42.3
Time Lag	1.372	1.198	1.093
	(1)-(2) 0.174	(2)-(3) 0.105	(1)-(3) 0.279
Uncorrected Individual Standard Deviation of Time Lag	0.075	0.076	0.083

If the standard deviations of the three populations from which these samples were drawn were known to be the same, the significance of the differences could be determined by the Student "t" Test.[1] The fact that there is no significant difference between the observed standard deviations can be established by the "z" Test and it appears that the use of the "t" Test is justifiable. The probabilities, P, obtained from this test, are those of obtaining differences as great or greater than those observed if the differences are due to the operation of chance causes in a single statistical population. A probability of one twentieth or smaller is often taken as the proper significance level in this type of experiment. The probabilities are given in Table VI.

The large fin diagonal results in a range which is different from that of a drum fin on a significance level of 0.04, and a time of flight which is different from that of both the drum fin and the small box diagonal on a level of 0.01. In trials of two types of fin assembly, the joint significance levels, although not multiplicative, must be considered as evidence from two trials in such a way that two experiments each resulting in a probability level of one fifth would be presumed different. It appears, therefore, that each of the three types of fin have different ballistic characteristics.

The ranges and times of flight of all three types of bombs show a high degree of consistency. The proof observer's comments on the observable yawing and rotation of the bombs are shown in Table VII.

1. The "t" Test and the procedure employed in making it are described in R. A. Fisher, Statistical Methods for Research Workers," Chapter V.

TABLE VI

RANGE

Difference	Large Fin Diagonal Minus Small Fin Diagonal	Small Fin Diagonal Minus Drum Type Fin	Large Fin Diagonal Minus Drum Type Fin
t	1.49	1.81	2.49
P	= 0.17	= 0.10	= 0.04

TABLE VI

TIME OF FLIGHT

Difference	Large Fin Diagonal Minus Small Fin Diagonal	Small Fin Diagonal Minus Drum Type Fin	Large Fin Diagonal Minus Drum Type Fin
t	3.52	2.05	4.30
P	< 0.01	= 0.07	< 0.01

TABLE VII

ORDNANCE OBSERVER'S RECORD

FLIGHT CHARACTERISTICS

100-lb. Concrete Practice Bombs

	Oscillation			Rotation		
Date	Large Fin Diagonal	Small Fin Diagonal	Drum Fin	Large Fin Diagonal	Small Fin Diagonal	Drum Fin
3/8/43	None None None None None	None None None None None		Slow Slow Slow Medium Slow	None Slow Slow None Slow	
4/24/43		None None . None None	None None None None None		None Slow Slow Slow	None None None Slow None

3. Conclusions.

It is concluded from the foregoing study that:

(1) A properly made drum-type fin, as shown in Figure 8, with a diameter equal to that of the bomb body and a suitably placed leading edge of the fin will be stable, will not have excessive rotation, and will have smaller form factors than a box-type fin of good design. The drum fin will have a smaller trail and time of flight, smaller differential effects and greater intrinsic accuracy than the better of the two box-type fins shown in this Figure.

(2) The width of the diagonal across a box-type fin is a factor of critical importance as was first shown by Col. H. H. Zornig from comparison of the form factors of bombs with the ratios of the diagonals across the fin box to the diameters of the bodies. The ratio of the form factors with respect to range for the bomb with small fin-box diagonal to the bomb with large fin-box diagonal is 0.93. The ratio of the form factors with respect to time of flight for the bomb with small fin-box diagonal to the bomb with large fin-box diagonal is 0.87. The box-type fin with small diagonal will have a smaller trail and a smaller time of flight, smaller differential effects and greater intrinsic accuracy than the box-type fin with large diagonal across the fin box.

(3) Although the Bomb, G.P., 100-lb., AN-M30 is fifteen pounds heavier than the concrete bombs, the concrete bombs have better ballistic performance. It seems that the absence of fuzes is the main source of the improvement in the case of the bomb with large fin box and is also an important helping factor in the other two cases.

(4) The drum-fin assembly results in performance of the concrete bomb which compares favorably with the Bomb, Practice, 100-lb., M38A2. The drum-fin assembly appears to have a smaller lift effect than the M38A2. Thus the range and time of flight of the drum-finned bomb are both smaller than the corresponding elements for the M38A2.

(5) The matching of both range and time of flight at one altitude and airspeed for two different bombs will depend upon meeting complex conditions upon the mass, diameter and six aerodynamic coefficients. It is probably possible at present only by the most extensive experimentation followed by analysis, interpretation of data and additional experimentation. This procedure, given a long enough series of experiments, is certainly possible but is, equally certainly, impractical. A good match at all altitudes and airspeeds for different bombs appears impossible of attainment.

(6) The concrete bomb has great merit as a practice bomb in spect to the degree to which the mass, position of the center of mass and the moments of inertia can be controlled within small tolerances about a design value. The loading of the Bomb, Practice, 100-lb., M38A2 is carefully specified in the front of bombing tables but field practice has resulted in wide departures from correct loading and in consequent systematic departures of the center of impact in practice from that in range bombing at the proving ground. The employment of liquid fillers has resulted in incomplete loading and in conspicuously erratic flight. The control of the loading of the concrete practice bomb is easily done and the behavior of the bomb can be made uniform. It can be arranged that no systematic departure of proving ground and field centers of impact occurs, and that the intrinsic dispersion of the concrete bombs can be made much smaller than would be possible in loading at the practice range.

IV. Recommendations

It is accordingly recommended that:

(1) The drum-type fin shown in Figure 5 be adopted for employment with the concrete practice bomb.

(2) In connection with fin design, the advantages of a drum-type fin of good design over a box-type fin be further explored.

(3) In connection with fin design, the advantages of a box-type fin with small diagonal over a box-type fin with large diagonal be further explored.

(4) The attempt to secure matching of both trail and time of flight at varying altitudes and air speeds of release for bombs of different shapes and mechanical constants be abandoned, and bombing tables be issued separately for different bombs unless the exterior contour, the mass, the center of gravity position and the moments of inertia are identical.

(5) Rigid materials, of which concrete is an example, whose density and uniformity can be carefully controlled, be employed whenever possible for loading practice bombs instead of fluid materials or materials for which identical density at various airfields is difficult to obtain.

(6) The mass, position of the center of gravity and moments of inertia of practice bombs, and tolerances corresponding thereto, be prescribed and controlled.

This report resulted from a conference following an acceptance test of concrete as a substitute material for steel, made under the direction of Lt. Col. R. G. Shinkle, of the Arms and Ammunition Proof Command, at which it was suggested to Mr. G. D. Mateer, Consulting Engineer, Concrete Products Co., Philadelphia, Pennsylvania, that he discuss the design of bombs with representatives of the Ballistic Research Laboratory. Mr. Mateer, redesigned and furnished for ballistic tests, bombs with center of gravity position, tail cone, and fin shape suggested by Dr. E. J. McShane, Mr. E. S. Martin, and the writers. The writers are greatly indebted to Dr. McShane and Mr. Martin for their suggestions on design, presentation of the data and critical review of this report and to Drs. E. P. Hubble and L. S. Dederick for encouragement of the project and suggestions which have been incorporated in the manuscript.

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APPENDIX A

MECHANICAL CONSTANTS OF BONES

TABLE OF MECHANICAL CONSTANTS OF INDIVIDUAL BOMBS EMPLOYED

Program Group Number	Date of Release Run Number	m Weight (Complete) as Dropped) (lbs)	$\bar{x}$ Distance of Center of Gravity from Nose (in.)	I_ϕ Moment of Inertia about Transverse Axis through Center of Gravity (lb. ft.^{2})
		Large Box		
1	3-8-43	102.4	15.42	51.66
2		102.9	15.49	51.88
3		103.2	15.41	52.28
4		101.1	15.37	51.09
5		102.8	15.32	51.73
6	4-24-43	103.1	15.53	51.91
7		103.9	15.52	53.04
8		101.7	15.52	51.34
9		102.3	15.45	51.97
10		102.2	15.41	51.38
		Small Box		
1	3-8-43	102.9	15.44	51.02
2		103.1	15.45	52.34
3		101.7	15.45	51.30
4		102.7	15.49	52.07
5		102.1	15.40	51.59
6	4-24-43	101.8	15.47	52.24
7		103.4	15.39	51.98
8		102.2	15.52	51.63
9	5-5-43	103.2	15.44	52.37
10		103.0	15.42	51.90
		Round Fin		
1	4-24-43	101.9	15.76	57.49
2		102.2	15.66	57.31
3		103.0	15.57	57.80
4		103.6	15.50	58.23
5		101.1	15.56	58.79
6		102.5	15.50	58.27

MEAN MECHANICAL CONSTANTS OF CONCRETE PRACTICE BOMBS, OF THE BOMB, G.P., 100-lb., AN-M30, AND AND THE BOMB PRACTICE, 100-lb., M38A2

	m Weight (Complete as Dropped) (lbs.)	$\bar{x}$ Distance of Center of Gravity from Nose (in.)	I_m Moment of Inertia about Transverse Axis through Center of Gravity (lb.ft.^{2})
Bomb, Practice, 100-lb., M38A2			
Mean	99.3	18.14	76.06
Standard Deviation	0.85	0.24	1.31
Maximum	102.0	18.76	79.50
Minimum	98.0	17.75	72.64
Number of Bombs	99	99	99
Bomb, G.P., 100-lb., M30 (Aluminum Fins)			
Mean	117.3	14.07	66.33
Standard Deviation	0.89	0.16	0.60
Maximum	119.3	14.27	67.21
Minimum	115.3	13.72	64.62
Number of Bombs	25	10	25
Bomb, G.P., 100-lb., M30 (Steel Fins)			
Mean	117.6	14.04	65.91
Standard Deviation	0.75	0.25	0.81
Maximum	118.8	14.36	68.16
Minimum	115.8	13.70	64.76
Number of Bombs	19	19	19
Large Fin Diagonal			
Mean	102.6	15.44	51.88
Standard Deviation	0.76	0.067	0.50
Maximum	103.9	15.53	53.04
Minimum	101.1	15.32	51.09
Number of Bombs	10	10	10

	m Weight (Complete as Dropped) (lbs.)	$\bar{x}$ Distance of Center of Gravity from Nose (in.)	I_m Moment of Inertia about Transverse Axis through Center of Gravity (lb.ft.^{2})
Small Fin Diagonal			
Mean	102.6	15.45	51.84
Standard Deviation	0.58	0.037	0.43
Maximum	103.4	15.52	52.37
Minimum	101.7	15.39	51.02
Number of Bombs	10	10	10
Drum Fin			
Mean	102.9	15.59	57.98
Standard Deviation	0.60	0.072	0.39
Maximum	104.1	15.76	58.72
Minimum	101.9	15.50	57.31
Number of Bombs	6	6	6

APPENDIX B

FIRING RECORD SHOWING DIFFERENCES
BETWEEN THE RANGES AND TIMES OF
FLIGHT OF THE BOMB, G.P., 100-lb.,
AN-M30 AND AN EXPERIMENTAL 100-lb.
PRACTICE BOMB WITH A DRUM-TYPE FIN

vlg/lrb

ABERDEEN PROVING GROUND, MARYLAND   LOT

OBJECT OF FIRING: Comparison of STD M30 Bomb
and
Concrete Bomb with Round Fin

DATE OF FIRING   3/4/43
FIRING RECORD NO.
SHEET 1 OF 1
O.P. NO.
O.O. FILE
A.P.G. FILE
W.O. NO.   323-1

Bomb No.	Bomb with longest Range	Bomb with longest time of flight	Flight of M30	Flight of concrete bomb	Difference in range (ft.)	Difference in time of fall (sec.)	
1	same	together	good		none	none	
2	same	together		good	none	none	
3	concrete			good	150		
4		M30	oscillated			0.46	
5	concrete	together		good	140	0.00	
6		together	good				
7	concrete	concrete		good	15		
8			good			0.15	

Bomb #4   Time of fall: 25.55 secs.
     5   Time of fall: 25.56 secs.
     8   Time of fall: 25.59 secs.

Bomb #1   100' left of No.2
     3   40' left of No.4
     5   110' right of No.6
     7   85' left of No.8

Bombs released from a B-18 airplane flying at an altitude of 10,000', in salvos of two, 1 each of STD M30 and concrete bombs.

Concrete bombs were painted yellow and equipped with circular fins and M30's painted o.d.

Present for Test:

Mr. Mateer) Concrete Product Co.
Mr. Woolery)

Lt. Olson